2009

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Thesis Proposal

Manoa Elementary School

[THESIS PROPOSAL]

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Executive Summary

The current design of the Manoa Elementary School's systems was based off of various detailed design objectives that are described in this report. These design objectives in conjunction with standards such as ASHRAE Standards 55, 62.1 and 90.1 and the funding available dictated the level of complexity of the mechanical system designed. All requirements used in design were used to develop an energy model to aid in predicting the system performance.

For the proposed analysis of alternative systems for the building, energy saving systems such as geothermal heat pumps, air-side heat pumps in conjunction with a re-designed primary natural ventilation system will be the focus of the primary research. Breadth topics considered that impact the performance of the mechanical system is the components of the architectural design such as glazing and the building envelope as well as the effect of daylighting.

Ground source heat pumps were considered as a design alternative due to their efficient use of energy. Two different types of ground source heat pumps will be considered for this analysis. These systems are a direct exchange heat pump system and a well system. Factors such as initial cost and operating cost will be a focus of evaluating the benefit of using this system instead of the designed system.

Air-side heat pumps were also considered as an alternative system for design. The high COP of this system for mild climates makes this system seem beneficial for this application. Comparison of this system to the performance of the ground source and designed system will be the focus of the analysis.

Natural ventilation is already implemented into the design of the building, but as a passive system. An active design system which uses the appropriate design methods as well as automated controls above the space occupants will be considered. Detailed calculations of the benefits of this system will be done to determine if the benefits of this system are worth the cost in design.

The architectural components that affect the building envelope will be considered for the analysis. A redesign of the glazing of the building may be necessary due to the natural ventilation analysis. Calculations for the effectiveness of the natural ventilation system are based on minimum window opening size. From Technical Report I, the 62.1 analysis determined that not all of the designed windows meet the minimum requirements to utilize natural ventilation. Another major component of the architectural design that affects the mechanical system is the design of the building envelope. Heat gained and released into interior spaces by the building materials will be considered for research.

A daylighting analysis will also be performed to determine the effect it will have on the mechanical system of the building. A cost analysis savings of this system will determine if an in depth design of a daylighting system will be beneficial for the mechanical system. Substantial savings by the implementation of the system will reduce the electrical cost of the building.

System Design

Design Objectives

Architecture

The design of Manoa Elementary School had very specific architectural and system design objectives. The building site was 3.1 acres of a 10 acre community sports complex located in a Philadelphia streetcar suburb. The design of the school required four classrooms for each grade level, kindergarten through fifth grade. This requirement along with the objective to maximize the amount of usable athletic field space resulted in a three story classroom wing constructed at a height which did not exceed local zoning ordinances. The utilization of the cafeteria as both a stage area and a sub divisible large group instructional area created a spatially efficient building footprint. To further minimize the building's impact on the neighborhood the building envelope utilizes a mixture of reflective zinc colored metal panels which decrease the apparent mass of the building by allowing it to assume the color of the surrounding environment.

Structural

Structural design objectives utilized were to minimize cost and construction duration. A reinforced masonry bearing and pre-cast concrete plank structural system were utilized for the classroom wing which also limited the overall height of the building to meet the zoning requirement of 30 feet.

Sustainability

Cost effective and environmentally protective sustainability strategies were incorporated into the architectural and systems design. Sustainable materials and finishes such as bamboo wainscot and acid etched and sealed concrete floors in circulation spaces. To reduce the load on the mechanical systems, sustainable design features such as insulated glass windows and doors, DDC Building Automation System, energy recovery systems, lighting control system which includes occupancy sensors, high efficiency indirect/direct lighting and daylighting were utilized.

Mechanical

The mechanical design objectives for Manoa Elementary School were relatively straight forward. The primary design objective for the HVAC system was to provide adequate heating and cooling to conditioned spaces while complying with ASHRAE Standards 55, 62.1 and 90.1. Another design objective was to control the humidity of spaces in order to decrease mold and mildew growth and improve the indoor air quality of the space.

Design Factors

Site

The location of the building in the heart of a residential community and within the center of a community sports complex provided many issues for the design. One of the main design concerns was maximizing the amount of athletic field space available for the community. This was achieved by utilizing a subsurface storm water detention system, hard surface playground that doubles as event parking and the efficient building layout described in the architectural objectives above. Noise generated by the mechanical systems was another issue of concern. Great effort was made in the design process to minimize the impact of noise generated by the mechanical systems to the surrounding community.

Cost

Manoa Elementary School is one of five elementary schools in the Haverford Township School District. As a public school, all funds for the construction of the new building were obtained through tax dollars or donations. As such, the total cost of the building was limited to the amount allotted by the Pennsylvania Department of Education though taxes and donations.

Major Equipment

Manoa Elementary School was designed to utilize several different mechanical system types. This was accomplished due to the fact that it houses several different types of spaces. These systems include four rooftop air handling units with energy recovery systems, one indoor air handling unit, a make-up air unit, 5 split system packaged rooftop air handling units and two duel fuel boilers. Two of the rooftop air handling units are variable volume outdoor air units and serve Wing A as shown in Figure 1. The other two rooftop air handling units in conjunction with the indoor air handling unit are constant volume systems that condition the classroom, office, gymnasium and kitchen spaces of Wing B which can be seen in Figure 2. The make-up air unit serves the kitchen and is a constant volume system that serves to replace the air exhausted from the space. The five air-cooled ductless split system units are two speed constant volume units that serve to condition the electrical and data distribution rooms in the Classroom Wing A.

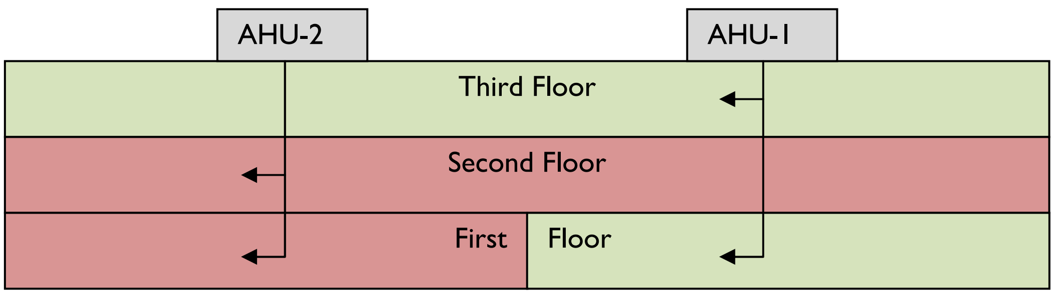

Figure 1: Wing A AHU Distribution Schematic

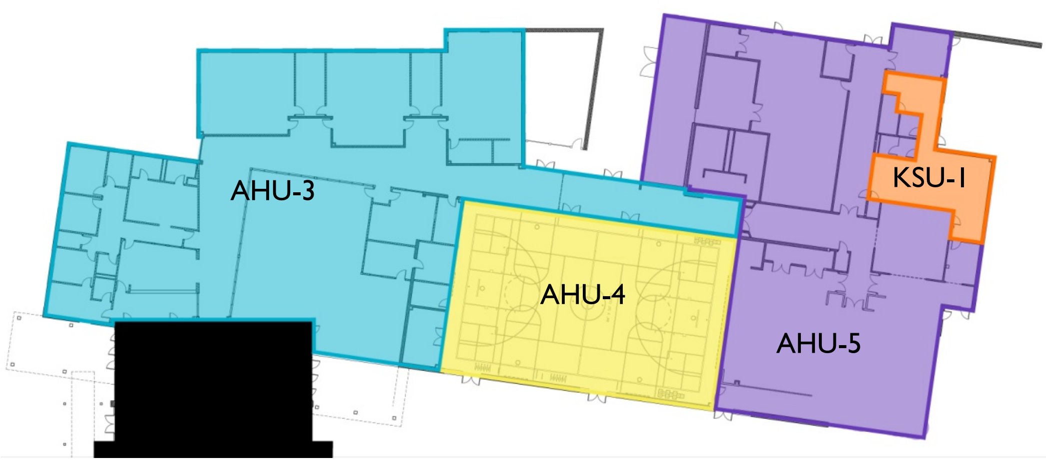

Figure 2: Wing B AHU Distribution

System Evaluation

Construction Cost

The construction cost of the mechanical system is 16.4% of the overall project budget. However, the utilization of energy recovery ventilators raises the complexity of the mechanical system. The increase in complexity to save energy does not substantially increase the cost of the mechanical system.

Operating Cost

The operating cost of the system determined from Technical Report II was determined to be $1.23 per square foot. This value is comparable to the value listed is ASHRAE Handbook of Applications 2007. Table 4 in Chapter 35 of this handbook gives a reference value of $1.09 for the 50th percentile. The data used by the authors of the handbook are from 2003 and are obviously outdated.

Space Requirements

Because of the design objective to minimize the building footprint, interior spaces needed to be used for educational purposes, not mechanical spaces. To minimize the impact of the mechanical equipment on the building rooftop air handling units and a mechanical penthouse were utilized. Implementation of other mechanical systems would take up far more floor space than the designed system.

Maintainability

The system requires a relatively knowledgeable maintenance staff in order to keep the system running. The system includes pumps, chillers, boilers and energy recovery units which all need supervision by a qualified staff. Since the air handling units are either on the roof or in the mechanical penthouse, components such as the coils, filters and fans requiring maintenance are easily accessible by the maintenance staff.

Indoor Air Quality Issues

A variable air volume system can create indoor air quality problems. Air delivered to the conditioned spaces is a mixture of the ventilation air and return air. The mixing with the return air can produce issues with the quality of the air distributed to the space. Ironically, another source for a reduction in the quality of air supplied to spaces can occur by the air filtration system. Leakage around the filters due to the inherent nature of filter construction or incorrect installation of the filters significantly reduces the performance of the filter and also reduces the air quality.

Proposed System Alternatives

The mechanical system described above was designed to be as efficient as possible while complying with the budget requirements. A further investigation of systems that reduce initial cost, operating cost, mechanical space or payback period will be researched further. An in depth analysis of modifications in these areas will be evaluated in the system redesign.

Several system alternatives appropriate for the building size and use will be investigated in order to determine their impact on the building energy use and for educational purposes. These alternatives include:

- Ground Source Heat Pumps
- Airside Heat Pumps

- Automated Natural Ventilation

These modifications will be analyzed to determine their impact on the initial cost, operating cost, mechanical space and payback period of these systems.

Ground Source Heat Pumps

An investigation of the effects of a ground source heat pump system will be researched. Both a direct exchange and a well type system will be compared to determine the different effects on the building systems. The main focus for the comparison of systems will be their impact on the initial cost, operating cost and impact on the square footage of the building. Another benefit of this system is it reduces the noise impact of the system to the environment by eliminating the need for compressors outside. Environmental noise reduction was a primary concern for the design team because the school is located in the center of a residential community.

The direct exchange heat pump system has several benefits as well as drawbacks that will be investigated. The primary benefits of the system is that it is significantly more efficient as well as a lower installation cost compared to a closed loop system. However, the system utilizes copper pipes as the underground heat transfer device which has a long life but the cost is of major concern as well as the greater use of refrigerant. The comparison of system costs and potential energy savings is of primary concern of analysis.

The vertical well system will be used to determine the increase in performance when compared to the direct exchange system. The main drawback of this system is the cost of boring holes 75-500 feet deep, however this system is beneficial for sites where space is a concern. The comparison of this system to the direct exchange and designed system is a concern of study.

Airside Heat Pumps

The consideration of using this system for analysis is based on the interest in comparing the system performance to that of the ground source heat pump systems. Estimated system performance in mild weather can be approximated to have a COP of 4 where the designed system has a COP of 2.7. The savings in energy efficiency makes this system a viable research option for an alternative design. Also, this system does not require the extensive excavation or underground piping requirements that the ground source heat pumps utilize therefore initial cost of the system would appear to be less that ground source heat pumps. The total cost comparison of this system to the ground source systems and the designed system is a definite area of interest for analysis.

Automated Natural Ventilation

Manoa Elementary School is already designed to utilize the benefits of natural ventilation; however it is only used as a backup to the mechanical ventilation system. Research and design for a primary natural ventilation system will be used to determine its impact on the energy use of the building. An analysis of the required glazing for each space will be done to ensure compliance with ASHRAE Standard 62.1 and study of the system controls will be detailed in the analysis.

Breadth Topics

Architectural

Improvements to the insulating capabilities of the building envelope will greatly affect the performance of the mechanical system. A tighter building envelope will result in less infiltration into the building which reduces the air handling capacity of the building. Another interest for the building envelope design is the heat gain and release into the spaces. If the envelope can be designed so that the heat is released into the space when it is in unoccupied mode the equipment loads will be reduced.

Another concern of design relates to the natural ventilation systems. Some of the designed operational windows may not be large enough to meet the requirements for natural ventilation therefore the amount of glazing will have to be increased which results in more solar heat gain.

Lighting

Although a fairly efficient lighting system was designed for the building, research into the reduction of electricity use by taking advantage of daylighting will be beneficial for mechanical system design. An analysis of the building orientation and solar angles as well as the performance of the glazing will be used in conjunction with lighting controls to determine the energy savings of this system. Saving electricity by dimming lights or not having them on all together will also reduce the load on the mechanical system.

Masters Applications

Knowledge gained from AE 557 Central Cooling and AE 558 Central Heating will be used when evaluating the systems described above. Central Cooling will aid in the analysis of the heat pumps when in cooling mode and compare the system to the variable air volume system currently designed. Central Heating will evaluate the heat pump heating performance and compare it to that of the two fossil fuel boilers proposed. AE 552 Indoor Air Quality will also be used to determine the effect on the interior air quality of each system as well as the effect the geothermal heating system has compared to the fossil fuel boilers designed.

Tools and Methods

Several different standards and computer programs will be used to determine the benefits of the alternative systems described above. ASHRAE standards describing methods of designing those systems as well as Trane Trace for modeling will be used to determine the performance as well as the energy savings for each different system as well as a combination of those systems with the breadth proposals.

Trane Trace will be the primary program used to determine the performance of the alternatives. This program is capable of modeling any kind of equipment configuration and an energy model can be used to compare the alternatives to the current system design. From this model a detailed report of the energy savings can be constructed and the benefits as well as the drawbacks of the different systems can be directly compared.

Microsoft Excel will be used to perform necessary calculations as well as create graphical comparisons of the different system performances. Any complex engineering calculations above the capabilities of Excel will be performed in Engineering Equation Solver which is programmed specifically

AGI or other lighting analysis programs in conjunction with ASHRAE Standard 90.1 will be used to evaluate the adequacy of the daylighting system for lighting interior spaces.

Preliminary Research

Clearinghouse, E. E. (2001). *Air-Source Heat Pumps.* Department of Energy.

This article by the U.S. Department of Energy details the operation, the system types, method of selection and installation, performance improvements, operation and maintenance measures for an air-source heat pump system. All major design points and considerations are detailed here as well as a detailed list of resources that can be utilized for further research.

Durkin, T. H., & Cecil, K. E. (2007). Geothermal Central System. *ASHRAE* , 42-48.

ASHRAE Journal published this article in order to outline the benefits of using a central geothermal heat pump system as well as its applications to schools. The article includes configuration schematics as well as graphs and tables detailing the application of this system to the design process. This article also discusses the energy savings and benefits for utilizing this system.

Honlness, G. (n.d.). *Energy Efficiency in Existing Buildings- Our Greatest Opportunity for a Sustainable Future.* Retrieved December 10, 2009, from www.ashrae.org: http://www.ashrae.org/aboutus/page/2372

This article written by the current president of ASHRAE discusses the effects of a sustainable design and the impact it has on our future. This article also discusses the design standards and techniques that can be used when attempting to design sustainable systems for new buildings.

MacMillan, J. (2007). Ground Source Heat Pumps in Schools. *ASHRAE* , 34-38.

This article details design considerations that can be used when designing ground source heat pumps and their applications to schools. Although this article specifically discusses the application of a closed loop system, it also states that the concepts detailed in this article are also applicable for other types of ground source heat pump systems.

Walker, A. (2008, June 3). *Natural Ventilation.* Retrieved December 10, 2009, from National Institute of Building Sciences Whole Building Design Guide: http://www.wbdg.org/resources/naturalventilation.php

The article on this website details the method of design for a natural ventilation system. A calculation procedure, design recommendations, materials and methods and analysis and designed tools are all specified in this article. All the information included in this article will be helpful when analyzing the performance of the proposed natural ventilation system.

Proposed Semester Schedule

Activity	Start	End
Preliminary Powerpoint Design	15-Dec	11-Jan
Begin Geothermal Heat Pump Analysis	11-Jan	22-Jan
Calculate System Initial Cost	22-Jan	29-Jan
Begin Air-Side Heat Pump Analysis	29-Jan	12-Feb
Calculate System Initial Cost	12-Feb	19-Feb
Begin Natural Ventilation Design	19-Feb	26-Feb
Calculate Cost Differences	26-Feb	1-Mar
Architectural Breadth	1-Mar	8-Mar
Spring Break	8-Mar	12-Mar
Daylighting Breadth	13-Mar	20-Mar
Final Report and Presentation	20-Mar	5-Apr
Final Report Due		7-Apr
Final Presentations	13-Apr	15-Apr

References

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ASHRAE. 2004, ANSI/ASHRAE, Standard 55-2004, Thermal Environmental Conditions for Human Occupancy. American Society of Heating Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, GA

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ASHRAE. 2007, ANSI/ASHRAE, Standard 90.1-2007, Energy Standard for Buildings Except Low-Rise Residential Buildings. American Society of Heating Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, GA

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H.F. Lenz Company. 2005-2007. Electrical Construction Documents. H.F. Lenz Company, Johnstown, PA.

McKissick Architects, Inc. 2005. Architectural Construction Documents. McKissick Architects, Harrisburg, PA.